哀牢山构造带南段风别山霏细斑岩地球化学特征及其锆石 U-Pb 年代学研究

孙崇波[1,2],李忠权[1],陈晓东[1,2],谢万洪[2],王道永[1]

1)国土资源部构造成矿成藏重点实验室(成都理工大学)、油气藏地质及开发工程国家重点实验室(成都理工大学),成都,610059;

2)四川冶金地质勘查局水文工程大队,成都,611730

内容提要:本文对云南省墨江县风别山霏细斑岩进行了锆石 U-Pb 年代学、岩石地球化学分析。LA-ICP-MS 锆石 U-Pb 测年显示,风别山霏细斑岩年龄为266.1±1.5Ma,形成于中二叠世晚期。岩石地球化学显示,风别山霏细斑岩 SiO_2 含量为75.04% ~ 81.88%,全碱(Na_2O+K_2O)含量为7.07% ~ 9.52%;岩石富集轻稀土,负铕异常明显(δEu:0.04 ~ 0.08),相对富集 Th、U,相对贫化 Sr、Ta、Cr、Au。通过图解显示风别山霏细斑岩形成于碰撞期后板内构造环境,说明哀牢山构造带的古特提斯支洋或弧后盆地在中二叠世晚期266.1 ± 1.5Ma 可能已经闭合。

关键词:霏细斑岩;锆石 U-Pb 年代学;岩石地球化学;造山期后花岗岩

西南三江地区一直以来以其独特的地质演化历史和出产丰富的金属矿产而受到众多研究者的青睐(Tapponnier et al. 1990;张旗等,1988,1995;Mo Xuanxue et al.,1994;莫宣学等,1998,2001,2006;钟大赉,1998;潘桂棠等,2003;Hou Zengqian et al.,2007;Khin et al.,2007;Liu Junlai et al.,2007;Deng Jun et al.,2010;刘翠等,2011;蔡永丰等,2014),古特提斯洋的演化是其中最为引人注目的课题之一(刘翠等,2011)。哀牢山造山带位于特提斯—喜马拉雅构造区与滨太平洋构造区的接触部位,兼具印支思茅地块和扬子地块两大构造单元的属性(钟大赉,1998;方维萱等,2002;Fan Weiming et al.,2010),而特提斯造山带以发育线延伸的构造行迹和岩浆岩带为特征,是研究多个岩石圈块体相互作用过程与动力学机制的经典地区(云南地质矿产局,1990;钟大赉,1998)。位于亲扬子的思茅地块和亲冈瓦纳的缅—泰—马地块之间的昌宁—孟连带是古特提斯多岛洋格局的主洋盆遗迹分布区,代表了古特提斯的缝合线(从柏林等,1993;Metcalf,2006;Wang Yuejun et al.,2010),对此认识,目前科学界比较一致,然而,金沙江—哀牢山构造带在晚古生代是否存在古特提斯支洋盆还存在争论,目前主要有两种观点:一种观点认为在金沙江—哀牢山—松马构造带发育了支洋盆(Jian Ping et al.,2009a,b;刘俊来等,2011);而另一种则认为思茅地块和扬子地块在泥盆纪前是一体的,晚古生代两者之间发育了古特提斯洋东缘弧后盆地(Metcalf,2006;Fan Weiming et al.,2010)。

基于以上争论及现有对哀牢山构造带火山岩的研究主要集中在中—基性岩石,关于该区花岗岩的研究报道较少(张玉泉等2004;李宝龙等,2008),而花岗岩是大陆地壳的组成部分,是地质学研究的重要课题,是研究地壳演化和古构造的一个有效手段(吴福元等,2007;王洪亮等,2007;赵海杰等,2010;费光春等,2010;邹光富等,2011),本文在前人的研究基础上,对位于哀牢山南段的风别山霏细斑岩(如图1)进行了主微量元素地球化学分析及 LA-ICP-MS 锆石 U-Pb 定年,进而讨论其形成环境及形成时代,以期为认识金沙江—哀牢山—松马构造带的演化提供新的证据。

1 区域地质背景及样品岩石学特征

哀牢山构造带整体呈 NW—SE 向,北西窄、南东宽,呈“喇叭”形展布于云南省中南部,向东南经

注:本文为中国地质调查局项目“西南三江成矿带南段基础地质调查”(编号:1212010880406、1212011120582)的成果。

收稿日期:2017-09-09;改回日期:2018-08-21;责任编辑:章雨旭。Doi:10.16509/j.georeview.2018.05.016

作者简介:孙崇波,男,1985年生,博士研究生,构造地质学专业。Email:1315333036@qq.com。

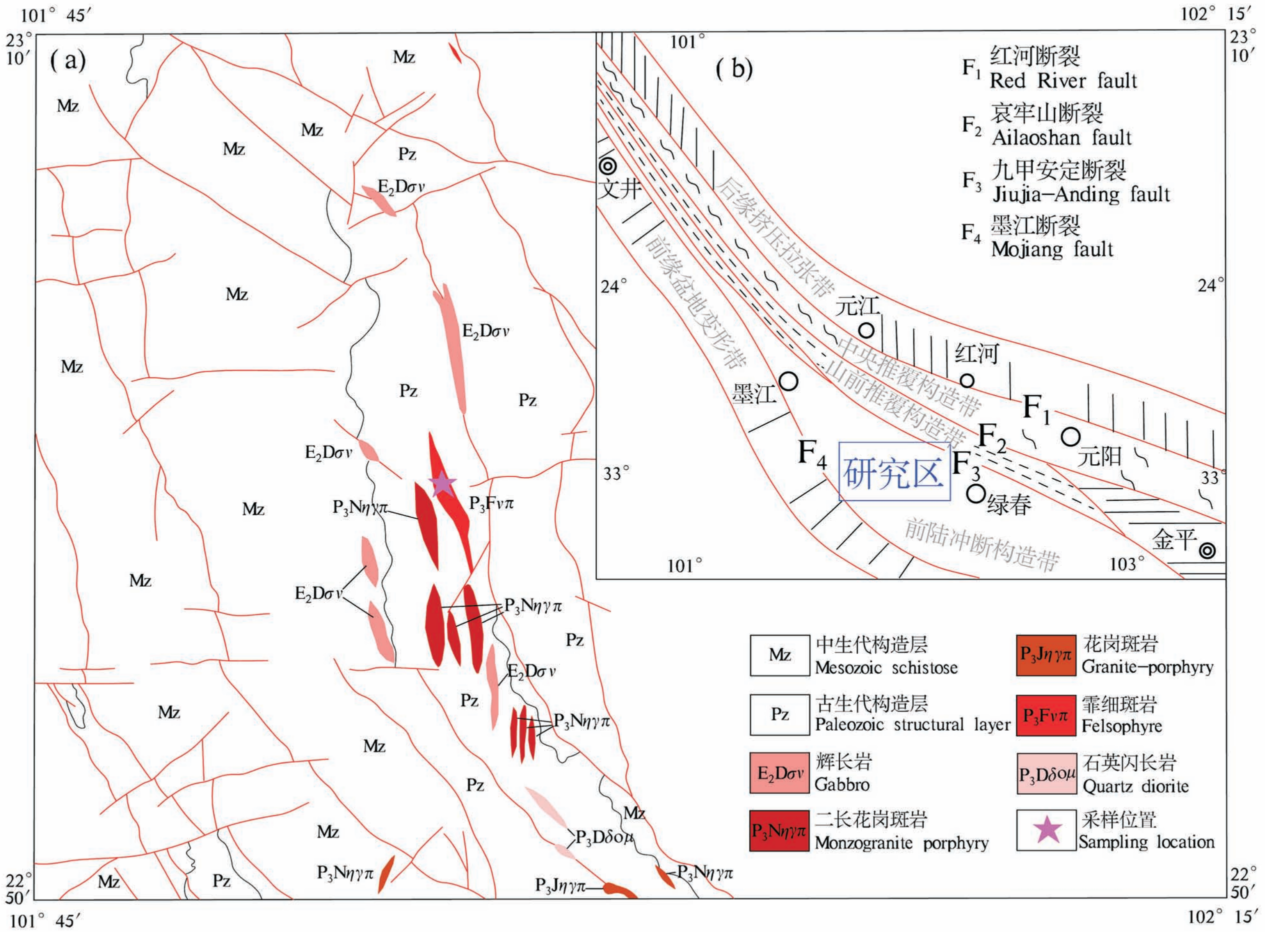

图 1 哀牢山构造带南段构造图(b)及研究区地质略图(a)

Fig.1 Structural map of the southern Ailaoshan tectonic belt (b) and geological sketch map of the study area (a)

元阳和金平县延伸进入越南境内与松马构造带连接,向西北经点苍山与金沙江构造带对应(钟大赉, 1998; 董云鹏等, 2000; 刘汇川等, 2013)。该构造带主要由四条主断裂及其夹持的三套不同性质的岩石建造组成,断裂自南西向北东依次为李仙江断裂、九甲—安定断裂、哀牢山断裂及红河断裂(云南地质矿产局, 1990)。哀牢山变质岩系是本区最古老的地层(钟大赉, 1998),其成了哀牢山的主体(李宝龙等, 2008)。哀牢山断裂带东侧为扬子地块,西侧为思茅地块。

本次研究的风别山霏细斑岩位于云南普洱市墨江哈尼族自治县大咪多—鲁红—波马断裂西侧,由3个独立岩体组成,总面积为10.73 km^2,属岩株及小岩枝,长宽比例近10∶1,其分布受构造控制明显,呈近南北向延伸,围岩为中—上二叠统羊八寨组。与围岩侵入接触界线较清楚,岩体边缘矿物粒度较细,蚀变较强烈;外缘围岩中因风化而现象模糊,个别位置可见烘烤边,岩石中残存褐红色带;泥质变质结晶为绢云母,砂屑多有重结晶。岩石呈浅灰白色、灰白色,蚀变后略带灰绿色,风化面多呈浅黄褐色—黄褐色,整体较松散,部分散化或泥化;含斑结构,基质霏细结构为主,可见花斑状、显微文象及球粒状结构;受蚀变影响,局部可出现交代蚕食结构、交代假像结构;风化强烈时呈非晶化假像,块状构造。少量斑晶(含量≤5)无序、不均匀分布,主要成分为石英(含量≤3)、中长石(含量≤2, An=30 ~ 32)、钾长石(含量≤2)。其中石英多呈无色细粒为主、少数中粒的较自形粒状或不规则的熔蚀港湾粒状,少数具自碎粒状,波状消光较强烈。中长石为细粒半自形板状—熔蚀不规则粒状,可见聚片双晶,但多因蚀变而模糊;裂隙发育,常为铁质浸染。钾长石形态与中长石类似,呈细粒半自形板状—熔蚀不规则粒状,但表面多蚀变或泥化而较混浊,可见卡式双晶、格子双晶或微纹结构,但薄片中未见其同时出

现。基质以霏细长英质为主组成,可见花斑状、显微文象及球粒状结构,副矿物见少许锆石。长英质重结晶不太明显,粒间或裂隙中可为水云母交代或充填。球粒呈 0.02~0.03 mm,长英质呈纤维状向心排列,十字消光明显,部分重结晶为长英质微粒集合体取代。岩石裂隙中可见细脉状碳酸盐、细粒长英质等充填。

长石类矿物电子探针成分分析(表 1)表明属斜长石类,其中斜长石中仍有少量正长石分子,其种类为钠长石、更长石;计算 An 值均低于实测值,表明蚀变对原始成分有所影响,其 Ca 质有一定的流失。

2　样品分析方法

对新鲜的样品通过人工重砂法选出锆石,在双目显微镜下挑选出晶形较好、无裂隙、无包体、干净透明的锆石颗粒,在玻璃板上将其用环氧树脂固定、抛光,然后拍摄反射光和透射光图像以及 CL 图像,以这些图像为依据选择最佳分析点—避开裂纹和包裹体的区域以及可能为不同世代过度的晶域。锆石 U-Pb 同位素分析在中国科学院广州地球化学研究所同位素地球化学国家重点实验室的 ICP-MS Elan6100DRC 激光探针上完成,同位素比值技术采用 GLITER4.0 程序(Jackson et al., 2004),普通 Pb 校正采用 Andersen(2002)介绍的方法,有关年龄计算及 U-Pb 谐和图绘制用 Isoplot(ver2.49)(Luding, 2001)程序完成。

全岩的主量和微量元素分析在四川省冶金地质岩矿测试中心的国家重点实验室完成。主量元素分析用 Rigaku RIX 2000 型荧光光谱仪(XRF),分析精度优于 1%~5%,具体实验流程见文献(Li Xianhua et al., 2005)。微量元素分析用 Perkin-Elmer Sciex ELAN 6000 型电感耦合等离子体质谱仪(ICP-MS),分析精度优于 2%~5%,详细实验方法见参考文献(刘颖等, 1996)。

3　锆石 U-Pb 年龄

风别山霏细斑岩样品 PM3005Z 中锆石呈无色至淡黄色,少数浅褐色,具色时核部色略深;自形短柱状为主,少数近粒状,个别长柱状(图 2);CL 图像中柱状者多具清晰的震荡环带,部分具边—核内部结构。30 个测点中的 2、3、6、8、11、12、13、14、17、18、20、26 及 28 为核部,5、18 及 25 震荡环带不太明显,其余测点均在震荡环带上。29 个测点的 $^{206}Pb/^{238}U$ 年龄值范围为 258.54~273.91Ma(表 2),经加权平均计算,获得锆石 Pb-U 加权平均年龄为 266.1 ± 1.5 Ma,置信度为 95%(图 3),代表霏细斑岩形成年龄,其形成于中二叠世晚期。

4　岩石地球化学特征

风别山霏细斑岩的主量元素含量、CIPW 标准矿物分子及主要参数见表 3。由表 3 可知 SiO_2 含量为 75.04% ~ 81.88%、平均 77.48%,全碱(Na_2O+K_2O)含量 7.07% ~ 9.52%、平均 8.01%。与中国霏细岩(黎彤等, 1965)比较,具有富硅钾、低钙的特点。其 CIPW 标准矿物分子中均含 C; A/NCK 多大于 1.0,为铝饱和型;σ<3.3,属钙碱性系列。根据邓晋福等(2015a),本文按照步骤对样品分别进行了投图,TAS 图解中样品均投点均位于 Irvine 分界线一下(图 4),属于亚碱系列;SiO_2—K_2O 图解中样品均位于高钾钙碱系列(图 5)。

表 1 墨江风别山霏细斑岩长石电子探针分析数据及晶体化学式

Table 1 electronic probe analysis data and crystal chemical formula of feldspar from the Fengbieshan felsophyre in Mojiang County

序号	样品号	Na_2O	K_2O	MgO	CaO	FeO	Al_2O_3	SiO_2	TiO_2	Cr_2O_3	MnO	NiO	总量
1	PM3005Z-1	11.89	0.05	0.01	0.02	0.00	19.12	67.80	0.01	0.05	0.00	0.01	98.97
2	PM3005Z-2	9.96	0.19	0.01	2.25	0.05	20.31	64.13	0.01	0.16	0.00	0.01	97.07
3	PM3005Z-3	11.50	0.06	0.00	0.03	0.01	19.01	68.34	0.03	0.02	0.03	0.00	99.02

	样品号	晶体化学式	端元式	An 值	矿物名称
1	PM3005Z-1	$Na_{1.2555}K_{0.0038}Ca_{0.0009}Mg_{0.0003}Fe_{0.0002}Al_{0.0455}[Al_{1.4134}Si_{2.5866}]O_8$	$Ab_{99.62}Or_{0.27}An_{0.11}$	0.11	钠长石
2	PM3005Z-2	$Na_{1.0419}K_{0.0147}Ca_{0.0876}Mg_{0.0003}Fe_{0.0018}Al_{0.0767}[Al_{1.5043}Si_{2.4957}]O_8$	$Ab_{97.92}Or_{1.10}An_{10.98}$	11.10	更长石
3	PM3005Z-3	$Na_{1.1969}K_{0.0044}Ca_{0.0011}Fe_{0.0005}Al_{0.0591}[Al_{1.3917}Si_{2.6083}]O_8$	$Ab_{98.53}Or_{0.33}An_{0.14}$	0.14	钠长石

注:成都理工大学国土资源部构造成矿与成藏重点实验室(2010 年)测试;测试条件:岛津 EPMA-1720, Beam Condition [AccV:15.0kV / BC:10.0nA / Beam Size:20μm / SC:8.8nA]

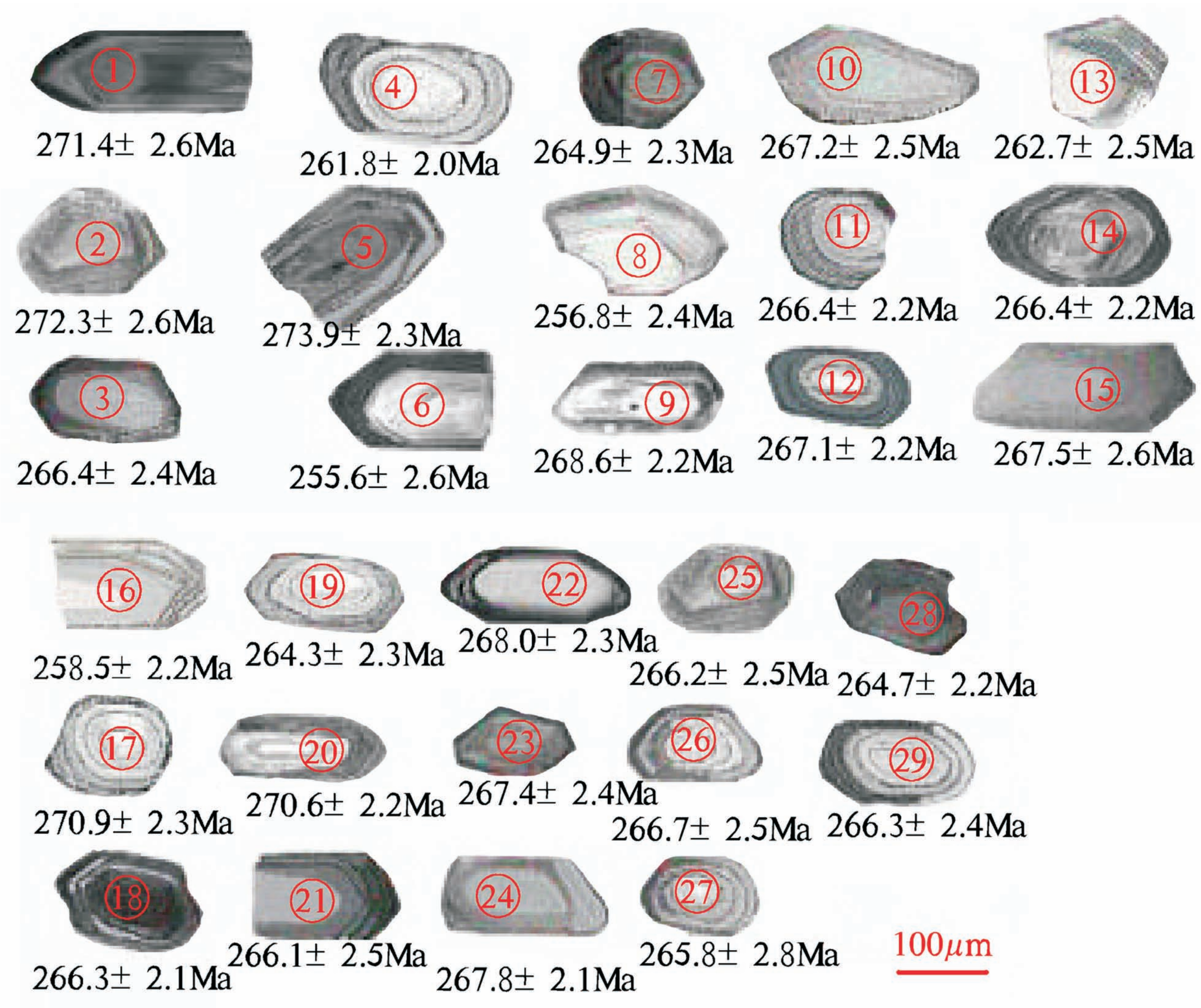

图 2 哀牢山构造带南段风别山霏细斑岩锆石颗粒 CL 图像

Fig 2 CL images of zircons from the Fengbieshan felsophyre in southern Ailaoshan tectonic belt

岩石分异指数(DI)为 92.91 ~ 99.24,平均为 96.82,岩体的固结指数(SI)为 0.67 ~ 8.03,小于 10,表明形成岩体的岩浆分异程度较高,分离结晶程度较好。综上所述,风别山霏细斑岩属于高钾钙碱性铝饱和系列。

根据阳离子参数特征,岩石投点落于造山期后 A 型花岗岩及其附近(图 6),在 Pearce 图解(图 7)上,投点全部落入板内型花岗岩区,因此认为其形成于造山期后陆内环境。

岩石的微量元素含量与世界相应岩类比较,Th、U、Hf、Sb 相对富集,Sr、Cr、Au 相对贫化,Sc、W、Rb 趋于富集,Ta、Co、Ni、Cs、Ba、Zr 趋于贫化,其它元素变化不定。反映出一定的岩浆及起源背景区的性质。经历强烈分异或非属下地壳—地幔源区,这与区域特点相当。Sr 负异常表明 Sr 主要进入斜长石中,并经历结晶分异。Cr 相对贫化,可能暗示源区岩石中长石类矿物的含量及其岩性特征一致。Rb 等元素趋于富集,Ta、Yb 等元素趋于贫化,显示一定的不相容性。这些元素的变化符合岩浆演化的一般规律。

岩石稀土元素含量及参数(表 4)表明:ΣREE 低于世界花岗岩,反映源区稀土亏损的特点,这与区域特点类似;ΣREE 平均值为 164.90,HREE 平均值为 28.45, LREE/HREE 平均值为 4.80,显示轻、重稀土元素存在一定的分馏。岩石 δCe 平均值 0.85, δEu 平均值为 0.06,表明岩石形成于岩浆演化、岩浆分异的晚期阶段;明显的 Eu 负异常很可能是由于大量斜长石的分离结晶所致,低 Sr 含量的特征可

表 2 哀牢山构造带南段风别山霏细斑岩 LA-ICP-MS 锆石 U-Pb 同位素测试结果

Table 2 LA-ICP-MS zircon U-Pb results of the Fengbieshan felsophyre in southern Ailaoshan tectonic belt

测点号	元素含量($\times10^{-6}$)			Th/U	同位素比值						同位素年龄(Ma)						谐和度(%)
	Pb	Th	U		$n(^{207}Pb)/n(^{206}Pb)$		$n(^{207}Pb)/n(^{235}U)$		$n(^{206}Pb)/n(^{238}U)$		$n(^{207}Pb)/n(^{206}Pb)$		$n(^{207}Pb)/n(^{235}U)$		$n(^{206}Pb)/n(^{238}U)$		
					测值	1σ	测值	1σ	测值	1σ	测值	1σ	测值	1σ	测值	1σ	
1	217	2699	4883	0.55	0.0525	0.0009	0.3112	0.0073	0.0430	0.0004	307.18	39.31	275.12	6.49	271.37	2.65	99
2	74	1305	1542	0.85	0.0530	0.0006	0.3152	0.0030	0.0432	0.0004	327.63	23.87	278.19	2.68	272.35	2.60	100
3	53	741	1216	0.61	0.0504	0.0007	0.2931	0.0035	0.0422	0.0004	212.37	31.30	261.00	3.11	266.45	2.44	101
4	190	1987	4541	0.44	0.0497	0.0003	0.2840	0.0019	0.0415	0.0003	180.32	12.22	253.82	1.66	261.84	1.96	100
5	156	2353	3260	0.72	0.0548	0.0005	0.3279	0.0027	0.0434	0.0004	403.62	19.98	287.96	2.35	273.91	2.27	99
6	319	4622	7448	0.62	0.0546	0.0003	0.3045	0.0032	0.0405	0.0004	395.58	12.71	269.90	2.85	255.63	2.62	99
7	167	2612	3710	0.70	0.0497	0.0003	0.2874	0.0022	0.0419	0.0004	180.29	12.43	256.48	1.96	264.89	2.34	101
8	127	2100	2785	0.75	0.0576	0.0006	0.3229	0.0031	0.0406	0.0004	515.16	21.34	284.10	2.70	256.81	2.39	102
9	52	778	976	0.80	0.0540	0.0006	0.3541	0.0038	0.0476	0.0004	369.62	25.87	307.81	3.34	299.72	2.32	98
10	63	972	1327	0.73	0.0544	0.0007	0.3191	0.0035	0.0425	0.0004	387.56	28.86	281.18	3.09	268.55	2.22	99
11	244	2130	5724	0.37	0.0499	0.0003	0.2914	0.0026	0.0423	0.0004	192.46	11.69	259.66	2.35	267.16	2.52	99
12	102	1505	2216	0.68	0.0506	0.0003	0.2946	0.0020	0.0422	0.0004	224.22	14.66	262.15	1.74	266.42	2.24	100
13	115	2525	2276	1.11	0.0564	0.0004	0.3287	0.0022	0.0423	0.0004	466.71	16.37	288.61	1.94	267.09	2.25	97
14	89	2071	1774	1.17	0.0626	0.0007	0.3591	0.0057	0.0416	0.0004	694.96	24.57	311.51	4.92	262.71	2.49	96
15	125	2856	2606	1.10	0.0569	0.0003	0.3310	0.0029	0.0422	0.0003	487.95	13.04	290.33	2.55	266.36	2.19	99
16	70	528	1665	0.32	0.0549	0.0007	0.3208	0.0056	0.0424	0.0004	409.29	26.72	282.54	4.96	267.45	2.64	100
17	136	2607	2886	0.90	0.0516	0.0003	0.2910	0.0028	0.0409	0.0003	266.61	14.81	259.34	2.49	258.54	2.17	101
18	294	3971	6305	0.63	0.0527	0.0003	0.3118	0.0029	0.0429	0.0004	315.75	14.96	275.58	2.59	270.87	2.27	99
19	250	395	6293	0.06	0.0625	0.0004	0.3635	0.0029	0.0422	0.0003	691.29	14.28	314.83	2.49	266.34	2.10	99
20	138	1900	2958	0.64	0.0590	0.0011	0.3402	0.0081	0.0418	0.0004	565.85	40.35	297.33	7.11	264.26	2.31	101
21	127	1825	2705	0.67	0.0509	0.0003	0.3008	0.0019	0.0429	0.0003	235.90	14.50	267.00	1.68	270.56	2.19	98
22	210	2518	4696	0.54	0.0569	0.0004	0.3305	0.0042	0.0421	0.0004	486.36	17.01	289.93	3.65	266.14	2.50	99
23	190	2918	4075	0.72	0.0505	0.0003	0.2953	0.0024	0.0425	0.0004	216.02	12.07	262.75	2.11	268.02	2.28	99
24	251	3367	5294	0.64	0.0638	0.0009	0.3729	0.0064	0.0424	0.0004	736.56	28.54	321.78	5.52	267.42	2.39	98
25	120	2267	2355	0.96	0.0651	0.0005	0.3807	0.0034	0.0424	0.0003	777.74	16.89	327.58	2.97	267.78	2.08	100
26	283	3379	6443	0.52	0.0511	0.0003	0.2970	0.0026	0.0422	0.0004	244.93	11.68	264.08	2.33	266.24	2.54	99
27	305	3791	6353	0.60	0.0679	0.0005	0.3953	0.0045	0.0422	0.0004	864.91	14.18	338.21	3.83	266.65	2.50	101
28	123	2247	2553	0.88	0.0523	0.0003	0.3036	0.0038	0.0421	0.0004	298.95	15.02	269.21	3.33	265.80	2.82	98
29	165	3107	3294	0.94	0.0688	0.0005	0.3974	0.0036	0.0419	0.0003	891.34	13.75	339.73	3.11	264.71	2.18	99
30	253	3163	5671	0.56	0.0545	0.0004	0.3167	0.0019	0.0422	0.0004	390.48	17.17	279.36	1.68	266.27	2.42	99

注:样品号 PM3005Z;测点号与锆石 CL 图像对应。

表 3 哀牢山构造带南段风别山霏细斑岩主量元素(%)和微量元素($\times10^{-6}$)分析数据

Table 3 Major (%) and trace element ($\times10^{-6}$) compositions of the Fengbieshan felsophyre

样号	PM3005H1	PM3005H2	PM3005H3	PM3005H4	PM3005H5	PM3005H6	PM3005H7	PM3005H8
SiO_2	77.15	78.02	76.69	77.13	78.12	75.04	75.78	81.88
Al_2O_3	12.45	11.41	13.45	12.71	11.60	13.40	13.65	9.95
Fe_2O_3	0.36	0.27	0.26	0.30	0.10	0.31	0.51	0.02
FeO	0.21	0.29	0.30	0.26	0.28	0.52	0.22	0.15
P_2O_5	0.017	0.022	0.018	0.017	0.015	0.015	0.019	0.027
K_2O	4.11	4.03	3.98	4.37	4.34	4.82	3.85	3.92
Na_2O	3.87	3.79	3.63	4.01	4.14	4.70	3.22	3.32
MgO	0.18	0.21	0.41	0.33	0.11	0.23	0.68	0.05
CaO	0.05	0.06	0.06	0.05	0.08	0.04	0.03	0.04
TiO_2	0.07	0.06	0.07	0.05	0.06	0.08	0.07	0.05
MnO	0.019	0.024	0.022	0.027	0.026	0.016	0.032	0.007
烧失量	0.87	1.12	0.98	0.77	0.68	0.69	1.17	0.54
总量	99.36	99.31	99.97	100.02	99.55	99.86	99.53	99.95
Q	39.20	40.91	40.09	36.81	37.52	28.91	42.05	47.68
An	0	0	0	0	0	0	0	0.02
Ab	33.15	32.43	30.87	33.98	35.27	40.00	27.67	28.26
Or	24.65	24.23	23.76	25.99	25.91	28.71	23.19	23.30
C	1.67	0.86	3.23	1.42	0.11	0.47	4.29	0.24
Hy	0.56	0.79	1.30	1.03	0.66	1.18	1.95	0.32
Il	0.13	0.12	0.13	0.10	0.12	0.15	0.14	0.10
Mt	0.47	0.40	0.38	0.44	0.15	0.45	0.58	0.03
Ap	0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.06
DI	97.00	97.57	94.72	96.78	98.70	97.62	92.91	99.24
SI	2.06	2.44	4.78	3.56	1.23	2.17	8.03	0.67
AR	4.25	4.90	3.32	4.38	5.87	5.65	2.78	4.96
σ	1.86	1.74	1.71	2.05	2.04	2.82	1.52	1.35
NK	7.98	7.82	7.61	8.38	8.48	9.52	7.07	7.24
A/CNK	1.142	1.066	1.295	1.113	0.995	1.029	1.434	1.018
Sc	2.47	3.01	2.77	2.63	2.59	3.47	2.90	0.50
Cr	4.27	3.98	5.66	5.87	4.06	3.43	5.73	6.98
Co	0.54	0.51	0.60	0.55	0.57	0.51	0.74	0.45
Ni	1.00	1.11	0.98	1.31	1.06	0.77	1.74	1.59
Zn	33.18	35.41	36.69	37.89	43.77	32.81	36.7	4.93
Rb	133.10	143.8	153.50	121.60	129.60	165.90	152.20	119.30
Sr	22.10	19.43	28.90	25.70	20.00	32.19	11.47	43.44
Cs	1.30	2.10	3.30	2.00	1.08	2.23	4.50	1.50
Ba	76.43	90.02	210.16	200.58	58.87	87.56	234.30	204.40
Zr	91.52	131.73	88.94	133.65	96.51	146.1	134.3	86.64
Ta	2.39	2.44	2.02	2.27	2.45	2.73	2.34	2.31
Th	19.88	28.74	30.12	44.08	32.42	49.53	43.76	15.54
U	7.20	7.38	7.81	8.09	7.09	8.61	7.43	7.21
Hf	3.99	4.13	5.26	6.11	4.05	6.34	5.88	3.64
Mo	0.54	0.66	0.71	1.11	0.34	0.44	1.35	0.59
W	1.57	1.91	2.01	2.35	1.63	2.78	1.82	1.44
Sn	9.82	10.22	13.43	15.78	8.39	12.61	18.24	7.98
As	1.83	2.24	0.99	2.76	0.78	2.14	1.64	11.48
Sb	0.65	0.92	1.12	1.00	0.47	0.53	1.30	1.14
Ag	0.043	0.050	0.048	0.056	0.055	0.05	0.045	0.058
Au	0.31	0.38	0.40	0.44	0.50	0.30	0.32	0.30
Cu	0.87	1.03	1.16	2.01	0.60	1.25	1.18	3.21

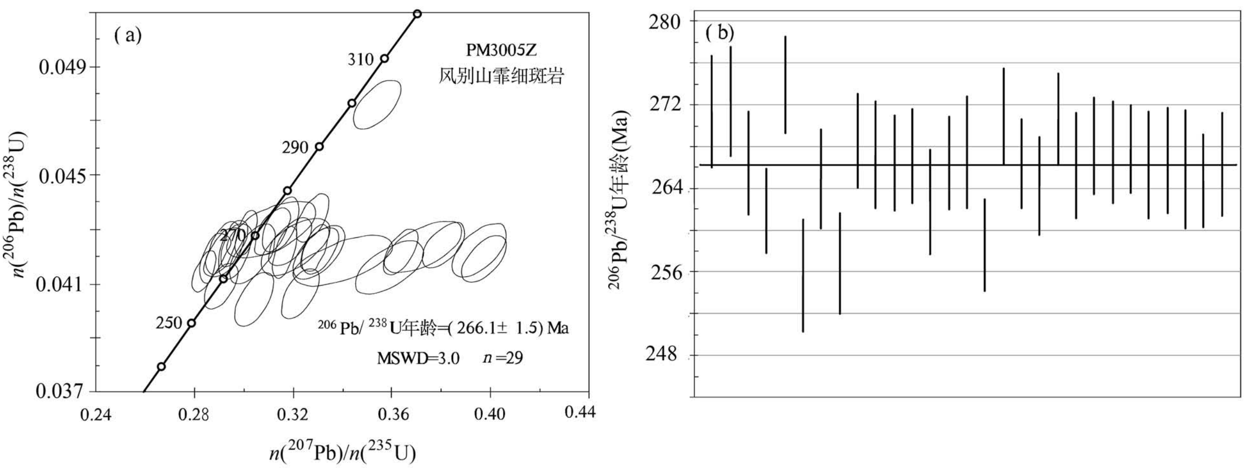

图 3 哀牢山构造带南段风别山霏细斑岩锆石 U-Pb 谐和图(a)及加权平均年龄图(b)

Fig. 3 U-Pb Concordia diagrams (a) and weighted mean age diagram (b) of zircons from the Fengbieshan felsophyre in southern Ailaoshan tectonic belt

为其佐证(Niu Yaoling et al., 2009)。在岩石稀土元素球粒陨石标准化配分模式图(图 8)中,属轻稀土富集型,负铕异常明显,稀土配分型式为富集"铕谷"右倾型。

5　讨论

5.1　风别山霏细斑岩形成时代

目前关于哀牢山构造带南段二叠世火山岩形成时代的观点还存在争议。云南地质矿产局(1990)对巴德轰花岗岩体测得黑云母 K-Ar 年龄为 207.0Ma 及 217.0Ma;刘翠等(2011)对绿春地区的流纹岩所测年龄为 247.3Ma;云南地质矿产局(1990)对新安寨花岗岩体研究,认为其侵位于晚三叠世,而刘汇川等(2013)对其进行了修正,认为其侵位于晚二叠世—早三叠世(251.6Ma);张英利等(2016)获得会泽地区典型岩浆岩成因碎屑锆石年

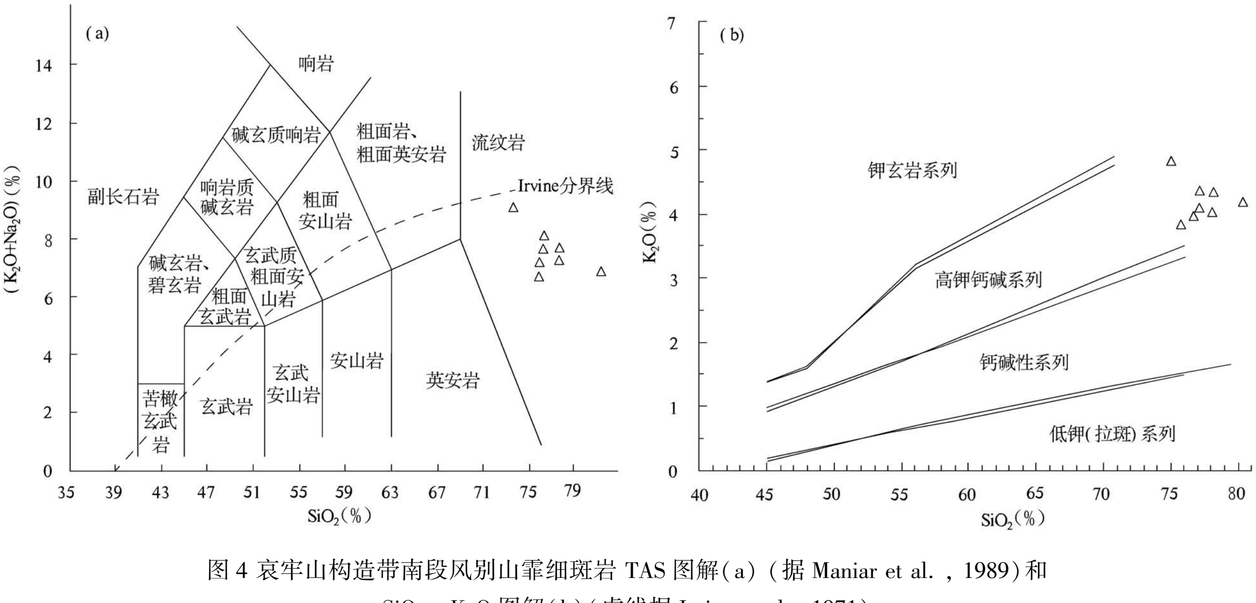

图 4 哀牢山构造带南段风别山霏细斑岩 TAS 图解(a)(据 Maniar et al., 1989)和 SiO_2—K_2O 图解(b)(虚线据 Irvine et al., 1971)

Fig. 4 TAS diagram (a) (after Maniar et al., 1989)) and SiO_2—K_2O diagram (b) (after Irvine et al., 1971) of the Fengbieshan felsophyre in southern Ailaoshan tectonic belt

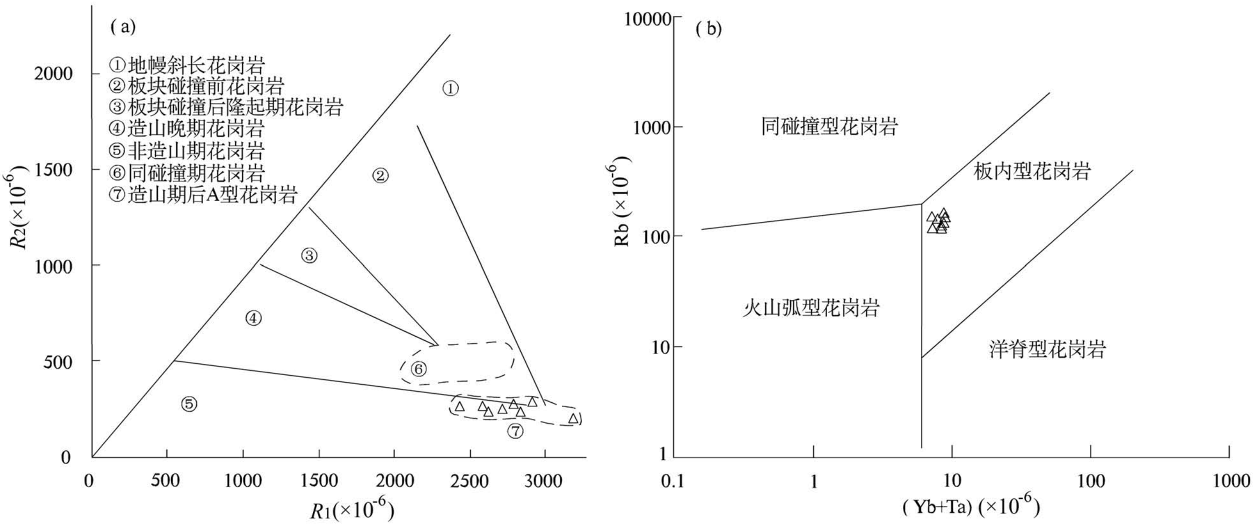

图 5 哀牢山构造带南段风别山霏细斑岩 R_1—R_2 图解(a)(据 Batchelor et al., 1985)和构造环境图解(b)(据 Pearce, 1984)

Fig. 5 R_1—R_2 diagram (a) (after Batchelor et al., 1985) and diagram of tectonic environment (b) (after Pearce, 1984) of the Fengbieshan felsophyre in southern Ailaoshan tectonic belt

龄为 257.0 ± 6Ma;赵德军等(2013b)获得该地区娘宗流纹斑岩 U-Pb 年龄分别为 263.1 ± 2.3 Ma、260.0 ± 1.7 Ma。本文对哀牢山构造带南段风别山霏细斑岩进行的 LA-ICP-MS 锆石 U-Pb 定年结果显示其加权平均年龄为 266.1 ±1.5 Ma,说明其形成于中二叠世晚期,与张英利等(2016)及赵德军等

表 4 哀牢山构造带南段风别山霏细斑岩稀土元素丰度($\times10^{-6}$)及主要参数

Table 4 REE analyses($\times10^{-6}$) of the Fengbieshan felsophyre in southern Ailaoshan tectonic belt

样 号	PM3005H1	PM3005H2	PM3005H3	PM3005H4	PM3005H5	PM3005H6	PM3005H7	PM3005H8
La	30.28	27.22	38.34	40.27	25.84	42.97	48.78	31.04
Ce	63.41	59.47	51.39	56.91	50.39	63.91	71.08	54.39
Pr	7.85	6.77	7.18	5.96	5.88	9.86	11.41	6.28
Nd	22.35	25.72	22.39	31.01	20.85	35.54	40.29	18.01
Sm	6.21	6.45	7.48	7.63	5.02	8.44	9.59	6.72
Eu	0.09	0.12	0.17	0.11	0.08	0.14	0.20	0.08
Gd	5.34	6.77	5.12	6.43	4.85	8.01	8.59	5.62
Tb	0.86	1.21	1.33	1.20	0.83	1.49	1.59	0.79
Dy	5.32	6.74	8.87	6.68	5.42	9.51	9.87	6.88
Ho	1.87	1.76	1.81	1.01	1.10	1.85	1.94	1.38
Er	3.93	5.49	4.07	3.82	3.38	5.65	5.78	4.07
Tm	0.93	0.67	0.83	0.72	0.59	0.96	0.98	0.88
Yb	6.33	5.41	5.10	5.03	5.88	5.94	6.58	6.01
Lu	0.57	0.71	0.88	0.80	0.65	1.03	1.03	0.86
Y	34.24	37.92	44.21	37.43	29.40	45.81	52.45	39.74
ΣREE	155.34	154.51	154.96	167.58	130.76	195.30	217.71	143.01
LREE	130.19	125.75	126.95	141.89	108.06	160.86	181.35	116.52
HREE	25.15	28.76	28.01	25.69	22.70	34.44	36.36	26.49
LREE/HREE	5.18	4.37	4.53	5.52	4.76	4.67	4.99	4.40
La_N/Yb_N	3.43	3.61	5.39	5.74	3.15	5.19	5.32	3.70
δEu	0.05	0.06	0.08	0.05	0.05	0.05	0.07	0.04
δCe	0.98	1.04	0.71	0.80	0.96	0.73	0.71	0.90

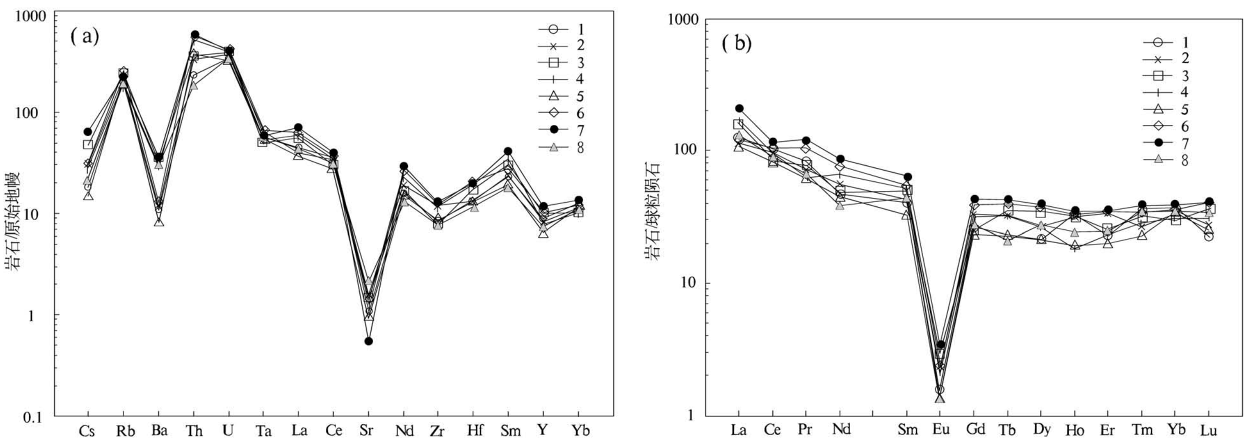

图 6 哀牢山构造带南段风别山霏细斑岩稀土元素配分模式图(a)和原始地幔标准化蛛网图(b)(标准值据 Sun et al.,1989)

Fig. 6 Chondrite-normalized rare earth element distribution pattern (a) and primitive mantle-normalized trace element spider diagrames (b) (normalization values from Sun et al., 1989) of the Fengbieshan felsophyre in southern Ailaoshan tectonic belt

(2013b)所得结果相近。

5.2 风别山霏细斑岩显示的构造意义

目前学术界对昌宁孟连带作为古特提斯洋主洋的观点比较一致,对其构造演化的各个阶段也做了大量的研究,如 Jian Ping 等(2009a,b)、Li Gangzhu 等(2012)等。但是对位于扬子板块和思茅印支板块之间的金沙江—哀牢山—松马构造带,在古生代到早中生代是古特提斯支洋还是弧后盆地还存在争议。刘翠等(2011)认为绿春地区 247.3Ma 的流纹岩形成于成熟岛弧向陆陆碰撞的过渡的构造环境;Zi J W 等(2012)认为金沙江白马雪山的花岗质侵入体(249.0Ma)是形成于岛弧向弧陆或陆陆碰撞转化的构造环境;刘汇川等(2013)则认为新安寨花岗岩体(251.6Ma)形成于岛弧向陆陆碰撞转化或者陆陆(陆弧)碰撞环境;赵德军等(2013a)认为仰宗流纹斑岩形成于造山期后阶段的后碰撞、应力松弛伸展环境。本文研究的风别山霏细斑岩岩体与上述岩体同处于哀牢山构造带中,其形成时代也与之相近,对风别山霏细斑岩岩体的主量元素组成在花岗岩构造环境判别图上同样投点于造山期后陆内环境,说明该岩体形成于造山期后陆—陆碰撞或陆—弧碰撞的环境。

前人对哀牢山构造带的古特提斯支洋或弧后盆地做了大量的研究,但在晚古生代到早中生代其构造演化时限仍然不确定。从柏林等(1993)认为哀牢山洋盆是在先期的陆内裂谷构造环境基础上发育起来的;骆耀南等(2001)认为早二叠世晚期哀牢山洋盆停止扩张,开始了自东向西俯冲,出现太宗—李仙江—带火山弧,至中二叠世晚期,哀牢山洋盆已经闭合,之后进入俯冲造山、高原隆升阶段。本文研究表明哀牢山支洋或者弧后盆地在古特提斯主洋向思茅印支板块之下俯冲及扬子板块西缘峨眉山地幔柱上侵的动力下,其南段在中二叠世晚期(266.1 ± 1.5Ma)可能已经闭合。

6 结论

(1)风别山霏细斑岩中锆石 U-Pb 加权平均年龄为 266.1 ± 1.5Ma,即其形成于中二叠世晚期。

(2)风别山霏细斑岩属铝饱和型,形成于造山期后陆陆碰撞或者陆弧碰撞的构造环境,表明哀牢山构造带的古特提斯支洋或弧后盆地在中二叠世晚期(266.1 ± 1.5Ma)可能已经闭合。

致谢:野外工作得到了成都理工大学邓江红教授的大力支持,论文得到了审稿专家和编辑的许多建设性意见,在此一并表示诚挚的感谢。

参 考 文 献 / References

(The literature whose publishing year followed by a "&" is in Chinese with English abstract; The literature whose publishing year followed by a "#" is in Chinese without English abstract)

蔡永丰, 王岳军, 刘汇川, 马莉燕, 邢晓婉, 刘雷. 2014. 哀牢山新远古代斜长角闪岩的形成时代、地球化学特征及其大地构造意义. 大地构造与成矿, 38 (1):168 ~ 180.

从柏林, 吴根耀, 张旗. 1993. 中国滇西古特提斯构造带岩石大地构造演化. 中国科学(D 辑), 23(11):1201 ~ 1207.

邓晋福, 冯艳芳, 狄永军. 2015b. 岩浆弧火成岩构造组合与洋陆转换. 地质论评, 61(3):473 ~ 484.

邓晋福, 刘翠, 冯艳芳. 2015a. 关于火成岩图解的正确使用:讨论与建议. 地质论评, 61(4):717 ~ 734.

董云鹏, 朱炳泉, 常向阳. 2000. 哀牢山缝合带中两类火山岩地球化学特征及其构造意义. 地球化学, 29 (1):6 ~ 13.

方维萱, 胡瑞忠, 谢桂青. 2002. 云南哀牢山地区构造岩石地层单元及其构造演化. 大地构造与成矿学, 26 (1):2 8 ~ 36.

费光春, 温春齐, 王成松. 2010. 西藏墨竹工卡县洞中拉铅锌矿床花岗斑岩锆石 SHRIMP U-Pb 定年. 中国地质, 37 (2):470 ~ 476.

李宝龙, 季建清, 付孝悦. 2008. 滇西点苍山—哀牢山变质岩系锆石 SHRIMP 定年及其地质意义. 岩石学报, 24 (10):207 ~ 211.

黎彤, 饶纪龙. 1965. 论化学元素在地壳及其基本构造单元中的丰度. 地质学报, 45 (1):82 ~ 97.

刘翠, 邓晋福, 刘俊来, 石耀霖. 2011. 哀牢山构造岩浆带晚二叠世早三叠世火山岩特征及其构造环境. 岩石学报, 27 (12):3599 ~ 3602.

刘汇川, 王岳军, 蔡永丰. 2013. 哀牢山构造带新安寨晚二叠世末期过铝质花岗岩锆石 U-Pb 年代学及 Hf 同位素组成研究. 大地构造与成矿学, 37 (1):87 ~ 98.

刘俊来, 唐渊, 宋志杰. 2011. 滇西哀牢山构造带:构造与演化. 吉林大学学报(地球科学报), 41 (5):1285 ~ 1303.

刘颖, 刘海臣, 李献华. 1996. 用 ICP-MS 准确测量岩石样品中的 40 余种微量元素. 地球化学, 25 (6):552 ~ 558.

骆耀南, 俞加龙. 2001. 西南三江地区造山演化过程及成矿时空分布. 矿物岩石, 33 (3):153 ~ 157.

莫宣学, 邓晋福, 董方浏, 等. 2001. 西南三江造山带火山岩—构造组合及其意义.高校地质学报, 7 (2):121 ~ 138.

莫宣学, 潘桂棠. 2006. 从特提斯到青藏高原形成:构造—岩浆事件的约束. 地学前缘, 13 (6):43 ~ 51.

莫宣学, 沈上越, 朱勤文. 1998. 三江中南段火山岩蛇绿岩与成矿. 北京:地质出版社: 1 ~ 128.

潘桂棠, 徐强, 侯增谦, 等. 2003. 西南“三江”多岛弧造山过程成矿系统与资源评价. 北京:地质出版社: 1 ~ 142.

王洪亮, 何世平, 陈隽璐. 2007. 北秦岭西段胡店片麻状二长花岗岩 LA-ICP-MS 锆石 U-Pb 测年及其地质意义. 中国地质, 34 (1): 17 ~ 25.

吴福元, 李献华, 郑永飞. 2007. Lu -Hf 同位素体系及其岩石学应用. 岩石学报, 23 (2) :185 ~ 220.

云南地质矿产局. 1990. 云南省区域地质志. 北京:地质出版社:400 ~ 450.

张旗, 潘国强, 李承东. 2007. 花岗岩构造环境问题:关于花岗岩研究的思考之三. 岩石学报, 23 (11):2683 ~ 2698.

张旗, 张魁武, 李达周, 吴海威. 1988. 云南新平县双沟蛇绿岩的初步研究. 岩石学报, 4(4):37 ~ 46.

张玉泉, 夏斌, 梁华英. 2004. 云南大平糜棱岩化碱性花岗岩的锆石特征及其地质意义. 高校地质学报, 10 (3):378 ~ 384.

赵德军, 陈洪德, 邓江红, 王道永. 2013a. 哀牢山造山带南段仰宗岩体地球化学特征及其构造环境. 矿物岩石, 33 (1):60 ~ 68.

赵德军, 陈洪德, 王道永, 王国芝, 李娜. 2013b. 哀牢山造山带南段中二叠世晚期娘宗岩体厘定. 地质科技情报, 32 (3) :19 ~ 25.

赵海杰, 毛景文, 叶会寿. 2010. 陕西黄龙铺地区碱性花岗斑岩及辉绿岩的年代学与地球化学:岩石成因及其构造环境示踪. 中国地质, 37 (1):12 ~ 27.

张英利, 王宗起, 王刚, 李谦, 林键飞. 2016. 上扬子会泽地区早三叠世飞仙关组砂岩物源特征:来自重矿物铬尖晶石和碎屑锆石的限定. 地质论评, 62 (1):54 ~ 72.

钟大赉. 1998. 滇川西部古特提斯造山带. 北京:科学出版社:1 ~ 231.

邹光富, 林仕良, 李再会. 2011. 滇西潞西邦木二长花岗岩 SHRIMP 锆石 U-Pb 年龄及其构造意义. 中国地质, 38 (1):77 ~ 85.

Andersent T.2002. Correction of common lead in U-Pb analyses that do not repert Pb-204. Chemical Geology, 192 (1 ~ 2):59 ~ 79.

Batchelor R A and Bowden P. 1985. Petrorgenetic interpretation of granitoid rock series using multicationic parameters. Chemistry Geology, 50:63 ~ 81.

Cai Yongfeng, Wang Yuejun, Liu Huichuan, Ma Liyan, Xing Xiaowan, Liu Lei. 2014&. Geochronological and geochemical characteristics of the Neoproterozoic amphibolite from Ailaoshan zone, western Yunnan and its tectonic implications. Geotectonica et Metallogenia, 38 (1):168 ~ 180.

Cong Bolin, Wu Genyao, Zhang Qi. 1993&. Triassic magmatism in the southern Lancangjiang zone, southwestern China and its constraints on the tectonic evolution of Paleo-Tethys. Chinese Academy of Sciences (Series D), 23 (11):1201 ~ 1207.

Deng Jinfu, Liu Cui, Feng Yanfang. 2015a&. On the correct application in the common igneous petrological diagrams: discussion and suggestion. Geological Review, 4 (61):717 ~ 734.

Deng Jinfu, Feng Yanfang, Di Yongjun, Liu Cui, Xiao Qinghui, Su Shangguo, Zhao Guochun, Meng Fei, Ma Shuai, Yao Tu. 2015b&. Magmatic arc and ocean—continent transition: discussion. Geological Review, 3(61): 473~ 484.

Deng Jun, Wang Qingfei, Yang Liqiang, Wang Yanru, Gong Qingjie and Liu Huan. 2010. Delineation and explanation of geochemical anomalies using fractal models in the Heqing area, Yunnan Province, China. Journal of Geochemical Exploration, 105 (3):95 ~ 105.

Dong Yunpeng, Zhu Bingquan, Chang Xiangyang. 2000&. Geochemistry of the two-type volcanic rocks from Ailaoshan suture zone and their tectonic implication. Geochemistry, 29 (1):6 ~ 13.

Fang Weixuan, Hu Ruizhong, Xie Guiqing. 2002&. Tectonolithostratigraphic units of the Ailaoshan area in Yunnan, China and their imply cations of tectonic evolution. Geotectonica et Metallogenia, 26 (1):28 ~ 36.

Fan Weiming, Wang Yuejun, Zhang Feifei, Zhang Yuzhi.2010. Permian arc—back-arc basin development along the Ailaoshan tectonic zone: Geochemical, isotopic and geochronol evidence from the Mojiang volcanic rocks, Southwest China. Lithos, 119 (3~4):553 ~ 568.

Fei Guangchun, Wen Chunqi, Wang Chengsong. 2010&. Zircon SHRIMP U-Pb age of porphyry granite in the Dongzhongla lead—zinic deposit, Maizhokungar County, Tibet. Geology in China, 37 (2):470 ~ 476.

Hou Zengqian, Khin Z, Pan Guitang, Xu Qiang, Hu Yunzhong and Li Xingzhen. 2007. Sanjiang Tethyan metallogenesis in SW China: tectonic setting, metallogenic epochs and deposit types. Ore Geology Reviews, 31:48 ~ 87.

Irvine T N, Baragar W R A. 1971. A guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Sciences, 8 (5): 523 ~ 548.

Jackson S E, Pearson N J, Criffin W L. 2004. The application of laser ablation of laser ablation-inductively coupled plasma-mass spectrometry to in situ U-Pb zircon geochronology. Chemical Geology, 211 (1~2):47 ~ 69.

Jian Ping, Liu Dunyi, Kroner A, Wang Yizhao, Sun Xiaomeng, Zhang Wei. 2009a. Devonian to Permian plate tectonic cycle of the Paleo-Tethys Orogen in southwest China (Ⅰ):Geochemistry of ophiolites, arc/back-arc assemblages and within-plate igneous rocks. Lithos, 113 (3~4):748 ~ 766.

Jian Ping, Liu Dunyi, Kroner A, Wang Yizhao, Sun Xiaomeng, Zhang Wei. 2009b. Devonian to Permian plate tectonic cycle of the Paleo-

Tethys Orogen in southwest China (Ⅱ):Geochemistry of ophiolites, arc/back-arc assemblages and within-plate igneous rocks and generation of the Emeishan CFB province. Lithos, 113 (3~4):767 ~ 784.

Khin Z, Stephen G P, Paul C, Clive B, Hou Zengqian. 2007. Nature, diversity of deposit tyes and metallogenic relations of South China. Ore Geology Reviews, 31:3 ~ 47.

Li Baolong, Ji Jianqing, Fu Xiaoyue. 2008&. Zircon SHRIMP dating and its geological implications of the metamorphic rocks in Ailao Shan—Diancang Mountain Ranges, west Yunnan. Acta Petrologica Sinica, 24 (10):207 ~ 211.

Li Guangzhu, Li Chusi, Ripley M E, Kamo S, Su Shangguo. 2012. Geochronology, petrology and geochemistry of the Nanlinshan and Banpo mafic—ultramafic intrusions: Implications for subduction initiation in the eastern Paleo-Tethys. Contributions to Mineralogy and Petrology, 164 (5):773.

Li Tong, Rao Jilong. 1965&. The bundance of chenIcalelements in the earth's crust and its majpr tectonic units. Acta Geologica Sinca, 45 (1):82 ~ 97.

Liu Cui, Deng Jinfu, Liu Junlai, Shi Yaolin. 2011&. Characteristics of volcanic rocks from Late Permian to Early Traissic in Ailaoshan tectono-magmatic belt and implications for tectonic settings. Acta Petrologica Sinica, 27 (12):3599 ~ 3602.

Liu Huichuan, Wang Yuejun, Cai Yongfeng. 2013&. Zircon U-Pb geochronology and Hf isotopic composition of the Xin'anzhai granite along the Ailaoshan tectonic zone in west Yunnan Province. Geotectonica et Metallogenia, 37 (1):87 ~ 98.

Liu Junlai, Cao Shuyun, Zhai Yunfeng, Song Zhijie, Wang Aanjian, Xiu Qunye, Cao Dianhua, Gao Lan, Guan Ye. 2007. Rotation of crustal blocks as an explanation of Oligo—Miocene extension in southeastern Tibet: evidenced by the Diancangshan and nearby metamorphic core complexes. Earth Science Frontiers, 14 (4):40 ~ 48.

Liu Junlai, Tang Yuan, Song Zhijie. 2011&. The Ailaoshan belt in western Yunnan: tectonic framework and tectonic evolution. Journal of Jilin University (Earth Science Edition), 41 (5): 1285 ~ 1303.

Liu Ying, Liu Haichen, Li Xianhua. 1996&. Simultaneous and precise determination of 40 trace elements in rock samples using ICP-MS. Geochemisty, 25 (6):552 ~ 558.

Li Xianhua, Qi Changshi, Liu Ying, Liang Xirong, Xie Liewen, Yang Yueheng. 2005. Petrogenesis of the Neoproterozoic bimodal volcanic rocks along the western margin of the Yangtze Block: New constraints from Hf isotopes and Fe/ Mn rations. Chinese Science Bull., 50: 2481 ~ 2486.

Ludwig K R. 2001. Sqind 1. 02: A User Manual. Berkeley: Berkeley Geochronological Cener Special publication: 1 ~ 219.

Luo Yaonan, Yu Jialong. 2001&. Orogenic evolutionary process and mineralize spatial and temporal distribution in Sanjiang area southwestern. Mineral Petrol., 33 (3):153 ~ 157.

Metcalf I. 2006. Paleozoic and Mesozoic tectonic evolution and palaeogeography of East Asia crustal fragments: The Korean Peninsula in context. Gondwana Research, 9 (1~2):24 ~ 46.

Maniar P D, Piccoli P M. 1989. Tectonic discrimination of granitoids. Geological Society of America Bulletin, 101 (5): 635 ~ 643.

Mo Xuanxue, Deng Jinfu, Lu Fengxiang, et al. 1994&. Volcanism and the evolution of Tethys in Sanjiang area, southwestern China. Journal of Southeast Asian Earth Sciences, 9 (4):325 ~ 333.

Mo Xuanxue, Deng Jinfu, Dong Fangliu. 2001&. Volcanic petrotectonic assemblages in Sanjiang orogenic belt, SW China and implication for tectonics. Geological Journal of China Universities, 7 (2): 121 ~ 138.

Mo Xuanxue and Pan Guitang. 2006&. From the Tethys to the formation of the Qinghai—Tibet Plateau: Constrained by tectono-magmatic events. Earth Science Frontiers, 13 (6):43 ~ 51.

Mo Xuanxue, Shen Shangyue, Zhu Qinwen. 1998. Volcanics—ophiolites and Related Mineralization in the Middle Southern Segment of Sanjiang Region. Beijing: Geological Publishing House: 1 ~ 128.

Niu Yaoling and O' Hara M J. 2009. MORB mantle hosts the missing Eu (Sr, Nb, Ta and Ti) in the continental crust: New perspectives on crustal growth, crust—mantle differentiation and chemical structure of oceanic upper mantle. Lithos, 112:1 ~ 17.

Pan Guitang, Xu Qiang, Hou Zengqian. 2003&. Archipelagic Orogenesis, Metallogenic Systems and Assessment of the Mineral Resources along the Nujiang—Lancangjiang—Jinshajiang Area in Southwestern China. Beijing: Geological Publishing House: 1 ~ 420.

Pearce J A, Harris N B L and Tindle A G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology, 25:956 ~ 983.

Sun S S, McDonough W F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. Geological Society, London, Special Publications, 42 (1):313 ~ 345.

Tapponnier P, Lacassin R, Leloup P H et al. 1990. The Ailao Shan/Red River metamorphic belt: Tertiary left-lateral shear between Indochina and South China. Nature, 343:431 ~ 437.

Wang Hongliang, He Shiping, Chen Junlu. 2007&. LA-ICP-MS zircon U-Pb dating of the Hudian gneissic monzogranite in the western segment of the North Qinling and its geological singnificance. Geology in China, 34 (1):17 ~ 25.

Wang Yuejun, Zhang Aimei, Fan Weiming, Peng Touping, Zhang Feifei, Zhang Yanhua, Bi Xiawu. 2010. Petrogenesis of Late Triassic Post-collisional basaltic rocks of the Lancangjiang zone, southwest China, and tectonic implications for the evolution of the eastern Paleotethys geochronological and geochemical constraints. Lithos, 120 (3~4):529 ~ 546.

Wu Fuyuan, Li Xianhua, Zheng Yongfei. 2007b&. Lu-Hf isotopic systematics and their applications in petrology. Acta Petrologica Sinica, 23 (2):185 ~ 220.

Yunnan Bureau of Geology and Mineral Resources. 1990#. Regional Geology of Yunnan Province. Beijing: Geological Publishing House: 400 ~ 450.

Zhang Qi, Pan Guoqiang, Li Chengdong. 2007&. Are discrimination diagrams always indicative of correct tectonic settings of granites: Some crucial questions on granite study (3). Acta Petrologica Sinica, 23 (11):2683 ~ 2698.

Zhang Qi, Zhang Kuiwu, Li Dazhou, Wu Haiwei. 1988. A preliminary study of Shuanggou ophiolite in Xinping county, Yunnan province. Acta Petrologica Sinica, 4(4):37 ~ 46.

Zhang Yuquan, Xia Bin, Liang Huaying. 2004&. Characteristics of zircons for dating from Daping mylonitized alkaline granite in Yunnan and their geologic implications. Geological Journal of China Universities, 10 (3):378 ~ 384.

Zhao Dejun, Chen Hongde, Deng Jianghong, Wang Daoyong. 2013a&. Geochemical features and tectonic setting of the Yangzong rock mass in the south part of Ailao Mountains Orogen. Mineral. Petrol., 33 (1):60 ~ 68.

Zhao Dejun, Chen Hongde, Wang Daoyong, Wang Guozhi, Li Na. 2013b&. Disintegration of Niangzong rock mass in the later period of the Middle Permian Epoch in the south part of Ailaoshan Orogen. Geological Science and Technology Information, 32 (3): 19 ~ 25.

Zhao Haijie, Mao Jingwen, Ye Huishou. 2010&. Geochronology and geochemistry of the alkaline granite porphyry and diabase dikes in Huanglongpu area of Shaanxi Province: Petrogenesis and implications for tectonic environment. Geology in China, 37 (1): 12 ~ 27.

Zhao Liying, Wang Zengqi, Wang Gang, Li Qian, Lin Jianfei. 2016&. Chromian spinel, zircon age constraints on the provenance of Early Triassic Feixianguan Formation sandstones from Huize area, upper Yangtze region. Geological Review, 62 (1): 54 ~ 72.

Zhong Dalai. 1998#. The Paleo-Tethyan Orogenic Belt in Western Yunnan and Sichuan. Beijing: Science Press: 1 ~ 231.

Zi J W, Cawood P A, Fan Weiming. 2012. Generation of Early Indosinian enriched mantle-derived granitoid pluton in the Sanjiang Orogen (S W China) in response to closure of the Paleo- Tethys. Lithos, 140 (5): 166 ~ 182.

Zou Guangfu, Lin Shiliang, Li Zaihui. 2011&. SHRIMP Zircon U-Pb dating of Bangmu admellite in Luxi, western Yunnan, and its tectonic implications. Geology in China, 38 (1): 77 ~ 85.

Petrogeochemistry and Zircon U-Pb Chronology of the Fengbieshan Felsophyre in Southern Section of Ailaoshan Tectonic Belt

SUN Chongbo[1,2], LI Zhongquan[1], CHEN Xiaodong[1,2], XIE Wanhong[2], WANG Daoyong[1]

1) *Key Laboratory of Tectonic Controls on Mineralization and Hydrocarbon Accumulation of Ministry of Land and Resources (Chengdu University of Technology), State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation (Chengdu University of Technology), Chengdu*, 610059;

2) *Hydro-Engineering Party of Sichuan Metallurgical Geology and Exploration Bureau, Chengdu*, 611730

Objectives: The Ailaoshan tectonic belt is situated at the contact site of Tethys—Himalaya tectonic region and coastal Pacific tectonic region. At present, it is still controversial that whether Jinshajiang—Ailaoshan tectonic belt exists paleotethys ramose ocean basin or not in late Paleozoic era. In regard to this dispute, we focus on the study of petrogeochemistry and zircon U-Pb chronology of the Fengbieshan felsophyre in Yunnan to evaluate geological evolution in late Paleozoic era in southern section of Ailaoshan tectonic belt.

Methods: Factitious heavy fraction was conducted to select zircons from the fresh sample of PM3005Z and well-crystallized, crackless, and transparent zircons were selected under the microscope, then photos of zircons were taken under reflected light and transmission light and CL image. The U-Pb isotope analysis was carried out at the laser probe of LA-ICP-MS Elan6100DRC in isotope geochemistry national key laboratory of Guangzhou Geochemical Institute. The analysis of major element compositions was completed with fluorescent spectrometer (XRE) of Rigaku RIX 2000. The analysis of trace element compositions was performed with inductively coupled plasma source mass spectrometer (LA-ICP-MS) of Perkin-Elmer Sciex ELAN 6000.

Results: LA-ICP-MS zircon U-Pb dating results show that the Fengbieshan granodiorite formed in the Late Permian (263.6 ±2.4Ma). The Fengbieshan granodiorite is characterized by SiO_2 62.10%~63.09%, alkali (Na_2O +K_2O) 6.28%~7.21%, and Na_2O>K_2O. Moreover, it is enriched in LREE and Sc, Hf, and depleted in Sr, Zr, Th, U, with negative Eu anomalies (δEu: 0.84~1.32).

Conclusions: According to the analysis data, we consider that the Fengbieshan granodiorite formed in the tectonic environment of island arc—continent or continental—arc collision, indicating that the branch of Paleo-Tethys Ocean or arc basin in Ailaoshan tectonic belt may have been closed in the Late Permian (263.6 ± 2.4Ma).

Keywords: felsophyre; zircon U-Pb chronology; petrogeochemistry; post-orogenic granite

Acknowledgements: This study was financially supported by the Chinese Geological Survey (No. 1212010880406, 1212011120582). We would like to express our thanks to professor Deng Jianghong from Chengdu University of Technology, who gave me much help for field work. We are also indebted to the teachers from editorial department, who offered me a number of important suggestions

First author: SUN Chongbo, male, born in 1985, doctor, structural geological specialty; Email: 1315333036 @ qq.com

Manuscript received on: 2017-09-09; Accepted on: 2018-08-21; Edited by: ZHANG Yuxu

Doi: 10.16509/j.georeview.2018.05.016